AN ACCOUNT OF THE RESEARCHES RELATING TO THE GREAT LAKES.

By J. W. SPENCER, [redacted].

[*From The American Geologist, Vol. XXI, February, 1898.*]

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By J. W. SPENCER, Toronto.

An old text book upon geology briefly says that the lake basins are due to movements of the earth's crust. What the movements were and how they affected the history of the great lakes was left a subject of discovery for recent years. In the mean while, theories arose as to their origin, the disposal or modification of which was fraught with difficulties as great as those of discovering the history itself. Ramsay had attributed the origin of the American lakes to glacial excavation;† Hunt, Newberry, Carll and many others had collected the evidence of buried channels occurring in the lake region. Gen. G. K. Warren‡ had followed up the observations of Prof. H. Y. Hind § in the history of the Winnipeg basin, and proposed the northeast warping as closing the Ontario basin, to such a degree that he may be considered the father of lacustrine geology. But the great impetus towards the investigation of the great lakes is due to Prof. J. S. Newberry, ‖ whose contribution was followed by one from Prof. E. W. Claypole.¶ To give a full account of the researches concerning the great lakes, and to tell how each author had contributed to the subject would make a very long chapter. As the present writer has been so closely connected with the pioneering study of the subject, and has announced progress from time to time before the American Association it seems a fitting opportunity to tell how his investigations have been influenced by his co-workers, leaving to others the narration of the most recent studies.

Newberry followed upon the lines of Ramsay in attributing the basins of the lakes to glacial excavations, yet there was a counter current in his writings which finally advocated that the glacial excavation had taken place only after their courses

*Read at the Detroit meeting of the A. A. A. S., 1897.

†Quart. Jour. Geol. Soc., Lond., vol. XVIII, pp. 185-204, 1862.

‡Appendix J., Rep. of the Chief of Engineers, U. S. A., 1875; Am. Jour. Sci. (3), vol. XVI, 1878, pp. 416-431.

§Report on the Assiniboine and Saskatchewan Exploring Expedition. By Henry Youle Hind. Toronto, 1859, pp. 1-20.

‖Geology of Ohio, vol. II, 1874, pp. 72-80.

¶On the pre-Glacial Geography of the region of the Great Lakes, E. W. Claypole. Can. Nat., vol. VIII, 1877, pp. 187-206.

had been pre-determined by river action. Adopting the teachings of Agassiz and Newberry, and going much farther, an influential school was developed which attributed the superficial features of the northern regions almost entirely to the action of continental ice,—in spite of the teachings of Lesley, Dawson, Whitney and others. The extreme views, as represented by Dr. G. J. Hinde,* made the ice plough dig out the St. David's, Dundas, and other valleys, irrespective of their direction, as compared with that of the ice flow. Such speculations were most common at the close of the eighth decade of the century, when the writer commenced his studies upon lacustrine history—concerning which his first paper was on the "Discovery of the Outlet of the Basin of Lake Erie, etc.,† (1881). The appearance of this "avant courier," was due to the enthusiastic reception given by Prof. J. P. Lesley to the writer's discovery of the reduction of rocky barriers beneath the superficial drift, between lake Erie and the Dundas valley, at the head of lake Ontario, indicating an outlet for the Erie basin by a channel, the lower end of which is deeply buried by drift deposits. Prof. Lesley pointed out that this discovery satisfied the necessity for some such outlet to the Erie basin, as Hunt and Newberry had found buried channels beneath the lake, and Mr. J. F. Carll had discovered that the drainage of the Upper Allegheny, and other streams, had been reversed, having flowed northward into the Erie basin in pre-glacial days.

The writer's paper referred to not only described the outlet of the Erie basin, but also showed that the Niagara river was not needed in ancient times. Shortly afterwards this idea was confirmed by Dr. Julius Pohlman ‡ who found that the Niagara channel was not sufficiently deep for the drainage of the buried valleys in the vicinity of Buffalo.

In the same paper, the valley-like features beneath the lake waters were analysed and established. But at that time

*Glacial and Interglacial strata of Scarboro Heights, etc. Canadian Journal, April, 1877, p. 24.

† Discovery of the Preglacial Outlet of the Basin of Lake Erie into that of Lake Ontario; with notes on the Origin of our Lower Great Lakes. By J. W. Spencer; Proc. Amer. Phil. Soc., XIX, 198, 2n., March 30, 1881, pp. 300-337.

‡The Life-history of Niagara. By Julius Pohlman. Trans. Am. Inst. Min. Eng.

the course of the ancient drainage could not be traced beyond the meridian of Oswego. The writer also objected to the theory of the glacial excavation of the basins on account of the stream-like sculpturing of the land, and the sub-lacustrine escarpments; and on account of the glaciation of the region being everywhere at sharp angles to the escarpments, whether above or below the surface of the lakes. These views and the discovery of the outlet for the ancient Erie basin confirmed the teachings of Prof. J. P. Lesley, who, from being a progenitor of the science of topography became the father of geomorphy, of which the lake history is one of the phases. In speaking of the origin of the lake valleys, Prof. Lesley* says: "For a number of years, I have been urging upon geologists, especially those addicted to the glacial hypothesis of erosion, the strict analogy existing between the submerged valleys of lakes Michigan, Huron and Erie, and the whole series of dry Appalachian 'valleys of VIII', stretching from the Hudson river to Alabama; also of Green bay, lake Ontario and lake Champlain, with all the 'valleys of II. and III.' One single law of topography governs the erosion of them all, without exception, whether at present traversed by small streams or great rivers, or occupied by sheets of water; the only agency or method of erosion common to them all being that of rainwater; not in the form of a great river, because many of them neither are nor ever have been great waterways."

Notwithstanding the short-comings, and what are now known to be errors of detail, the paper on the pre-glacial outlet of Erie attracted considerable attention as a new departure; and at the time Prof. James Geikie, who is well known to be one of the leading glacialists, expressed himself as follows, under date June 21, 1881: "I have always had misgivings as to glacial erosion of the great lakes, * * * and now your most interesting paper comes to throw additional doubt upon the theory in question. Possibly those who have upheld that view will now give in. Your facts seem, to me at least, very convincing." I never could understand how those great lakes of yours could have been ground out by ice. The

*Report Q4 of the Geological Survey of Pennsylvania, 1881, pp. 399-406.

physical conditions of the ground seem to me very unfavorable." Prof. G. K. Gilbert, on June 15, 1881, wrote: "My first geological field work was in the drift of the Erie basin, and the problem of the origin of the basins of the great lakes has always had great attraction for me. Had I been able to understand its solution, my working hypothesis would have been that which you have demonstrated so thoroughly. * * * The matter has certainly never received a demonstration until your paper appeared. * * *"

At this time the writer was struggling to find the outlet of the basins, and looked in every possible direction for buried channels without avail. While the St. Lawrence valley, beyond the outlet of lake Ontario, was evidently only a continuation of the drowned valley occupied by the lake, and while the lower St. Lawrence indicated an elevation of the continental region to more than 1,200 feet (when the cañon of the Saguenay was being excavated), the evidence of the local oscillation of the earth's crust was not yet forthcoming. The deep cañon of the Dundas valley, and the observations of Prof. Gilbert that the Irondequoit bay was drowned to a depth of 70 feet was taken as evidence of terrestrial oscillation, but later the writer found that the St. Lawrence, after leaving Ontario, was in part flowing over a valley buried or drowned to a depth of 240 feet; accordingly the Dundas and Irondequoit valleys were no evidence of local oscillation, which had to be found elsewhere.

In concluding a notice of this early work,* the modern aspect of the Niagara river was emphasized, and the valley of St. Davids was regarded as of inter-glacial origin—in deference to the prevailing theories of the time—in place of being, as is now known, the channel of an insignificant stream of greater antiquity. The Finger lakes of New York were explained as closed up valleys which had formerly drained the rivers of the highlands of New York, as for example Seneca lake, which has since been found to be the ancient course of Chemung and its tributaries. About this time the writer, from the data collected by the Geological Survey of Pennsyl-

*A short study of the Features of the Great Lakes, etc. J. W. Spencer. Proc. A. A. A. S., vol. XXX, 1881, pp. 131-146; and Surface Geology of the Region about the western end of lake Ontario. J. W. Spencer, Can. Nat., vol. X, 1882, pp. 213-236, and 265-312.

vania, pointed out the probability that the Monongahela and upper Ohio had formerly been reversed and drained into the Erie valley.* This hypothesis was afterward amplified by Dr. P. Max Foshay,† disputed by Prof. I. C. White; modified and confirmed by Mr. F. Leverett,‡ and finally, with some modifications, reconfirmed by Prof. I. C. White.§ In order to test the validity of his objections to the hypothesis of glacial excavation, the writer visited Switzerland and Norway for the purpose of personally observing the mechanical effects of modern glaciers, with the result that he saw in them only the agents of abrasion—the ice moulding itself round obstructions, or smoothing off irregularities, and not ploughing out channels.‖ Indeed, in a more recent visit to Norway, it became apparent that the great glacial valleys still preserve many base levels of erosion—the doctrine of which has not been applied to them, and consequently their history is as yet unwritten. The extreme views concerning glacial erosion, held a decade ago, are now greatly modified and do not belong to the present day.

In 1882, fragments of great beaches, and others which were delta deposits, were described as occurring about the western end of lake Ontario at various elevations from 500 feet above the lake down to its present level.¶ Other fragments of beaches had been known for many decades, the most notable of which were the ridge roads of New York state, that Prof. James Hall, as early as 1842, found to be rising gently upon proceeding eastward;** and the same was found to be true at the eastern end of lake Ontario. About this time Prof. Gilbert was studying the beaches of the western lakes, and Mr. Warren Upham those of the Winnipeg basin. The

*On the ancient upper course of the Ohio river emptying into lake Erie. Proc. Am. Phil. Soc., Phil., vol. XIX, 1881.

†Preglacial Drainage and recent Geological History of western Pennsylvania. Am. Jour. Sci., vol. XL, 1890, pp. 397-403.

‡Pleistocene fluvial plains of western Pennsylvania. Am. Jour. Sci., vol. XLII, 1891, pp. 200-212; and Further studies of the Upper Ohio basin. Am. Jour. Sci., vol. XLVII, 1894, pp. 247-283.

§ American Geologist, vol. XVIII, 1896, pp. 368-379.

‖ The erosive power of glaciers as seen in Norway. Geol. Mag., Lond., Dec. iii, vol. IV, 1887, pp. 167-173.

¶ Surface Geology about the region of the western end of lake Ontario, cited before.

** Geology of New York. Vol. IV, 1843, p. 351.

beaches in both places were found to record the evidences of gentle terrestrial movements. Following up his investigations, Prof. Gilbert connected the various fragments of a great beach upon the southern and eastern sides of lake Ontario, as far as Adams Centre, near Watertown, N. Y.,* and found that the old waterline was deformed to the extent of several hundred feet in proceeding northeastward. This was an admirable piece of work, which was invaluable to the writer, who extended the observations farther† and made use of them in measuring the amount of the long sought for terrestrial deformation at the outlet of lake Ontario, and found that these post-glacial movements were sufficient to account for the rocky barrier across the Laurentian valley, producing the basin which retains the waters of lake Ontario. The channels across this rocky barrier, however, were closed with drift deposits reaching to a depth of 240 feet. In thus establishing the ancient drainage of the Ontario basin, after years of observation, often representing but little progress, the phenomena of the basin were discovered without the glacial theory of erosion. Then the writer found that the drowned channels cross lake Huron, and passing through Georgian bay, continued beneath hundreds of feet of drift, eastward of the Niagara escarpment, and joined the Ontario valley a few miles east of Toronto. A similar channel (the Huronian) crossed the state of Michigan, passed through Saginaw bay, and over the sub-lacustrine escarpment, to the deeper channel of the Huron basin.‡ The Erie (Erigan river) drainage had been found to pass into the head of the Ontario basin. Thus was discovered the course of the ancient Laurentian river and its tributaries of antiquity. These upper basins were also affected by the terrestrial tilting recorded in the beaches, as well as by the drift obstructing them.

Prof. Gilbert, who had, many years before, mapped beaches at the head of lake Erie§ afterwards measured the

*Report of the meeting of the Am. Assc. Adv. Sci., Science, Sept., 1885, p. 222.

†The Iroquois Beach: a Chapter in the Geological History of Lake Ontario, by J. W. Spencer. Trans. Roy. Soc. Can., 1889, pp. 121-134. (First read before Phil. Soc., Wash., March, 1888.)

‡Origin of the Basins of the Great Lakes. Q. J. G. S. (Lon.), vol. XLVI, 1890, pp. 523-533.

§See Geology of Ohio, vol. II, 1874.

deformation recorded in the deserted shore at the eastern end of the lake;* while the writer surveyed the old water margins across Michigan, and on the Canadian sides of lakes Ontario, Erie and Huron, and in portions of New York.† After this, very little work was done upon the deserted shores for several years, when Mr. F. B. Taylor commenced his researches about the northeast portion of Georgian bay, lake Michigan, etc.;‡ and Dr. A. C. Lawson carried on similar observations north of lake Superior,§ and Prof. H. L. Fairchild in New York. The deserted beaches show but little terrestrial oscillation about the western end of lake Erie, but it increases towards the northeast and amounts to four to seven feet per mile.

With the surveys of the deserted beaches, new questions arose concerning the history of the lakes and of Niagara river, which forms an inseparable chapter. At the same time, opposing hypotheses presented themselves.

None of the beaches have been fully surveyed. They occur at various altitudes from near the greatest elevation of the land down to the levels of the lakes, and they have not always been separated from other Pleistocene deposits. While there are questions as to the higher forms, those from lower levels have undoubtedly been accumulated about extensive bodies of water—the character of which is the subject of disagreement. The writer has regarded them as accumulations at sea-level, and other observers as margins of glacial lakes, irrespective of their elevation. The theoretical aspect is not one likely to be settled speedily. Those who advocate the glacial character of the lakes have sought to terminate the beaches against morainic deposits to the northeast, but their

*The History of the Niagara River. 6th Rept. Com. State Res. Niag., Albany, 1890, pp. 61-84.

†The Iroquois Beach, etc., cited before. Deformation of the Iroquois Beach and Birth of Lake Ontario, Am. Jour. Sci., vol. XL, 1890, pp. 443-451; Deformation of the Algonquin Beach and Birth of Lake Huron, Ib., vol. XLI, 1891, pp. 11-21; High Level Shores in the Region of the Great Lakes, and their Deformation, Ib., vol. XLI, 1891, pp. 201-211; Deformation of Lundy Beach and Birth of Lake Erie, Ib., vol. XLVIII, 1894, pp. 207-212.

‡Numerous papers recently published in Am. Jour. Sci., American Geologist, and Bul. Geol. Soc. Am.

§Sketch of the Coastal Topography of the North Side of Lake Superior. 20th Report of the Geol. Sur. Minnesota, for 1891, pp. 181-289.

ice dams have been frequently thrown along lines beyond which the beaches have subsequently been traced. Thus Prof. Claypole* made ice dams in Ontario where open water, bounded by beaches, was afterwards found to prevail. At Adams Centre, Prof. Gilbert drew an ice dam for the Ontario basin, beyond which, however, the writer found that the old shore line extended, and this was later confirmed by Prof. Gilbert. Mr. Leverett made an ice dam at Cleveland, beyond which the writer has been informed by two observers that the beach extends, and Prof. Gilbert and Mr. Leverett described another glacial dam near Crittenden, N. Y., beyond which the beaches have been discovered by Prof. Fairchild. Another diagnosis of the glacial lakes is the occurrence of gravel floors over low divides, which are regarded as the outlets of them, and upon this feature alone many such lakes have been named. But the advocates of these glacial outlets have not explained how the terraces (at hundreds of feet above the drainage) upon the southern side of them are indistinguishable in character from those upon the northern side.† If these supposed outlets be evidence per se of glacial dams then the most perfect which the writer has ever seen may be found within 16° of the equator, at an altitude of less than 800 feet, suggesting that the Mexican gulf had a glacial dam, discharging into the Pacific ocean across the isthmus of Tehuantepec—a suggestion which no one would seriously consider. The writer has also presented the hydrostatic objections‡ to the impossible long continuance of some of the supposed dams, the location of which demands their drainage across ice itself, which would soon be penetrated by the warmer waters so as to reduce their level. By straightening out the deformation recorded in the deserted shore-lines, some of the beaches are shown to have undoubtedly been formed at sea-level.§ While recent surveys report the discovery of additional glacial lakes, or the splitting up of those

*Report of the meeting Am. Assoc. Adv. Sci. Science, Sept., 1895. p. 222.

†Channels over divides not evidence per se of glacial dams. J. W. Spencer. Bull. Geol. Soc. Am., vol. III, 1891, p. 491.

‡Post-Pliocene continental subsidence versus ice-dams, by J. W. Spencer. Bull. Geol. Soc. Am., vol. II, pp. 465-476, 1890.

§The Iroquois Beach, etc., cited before; and, Deformation of the Iroquois Beach, cited elsewhere.

first described under new names, the survey of the high level terraces in the mountain regions has suggested to the writer counterbalancing evidence of the occurrence of glacial dams, but this is a study which has been postponed, partly on account of the prejudice against post-glacial subsidence and partly on account of the writer's absorption in other questions of physical changes. Whatever may be the ultimate fate of the theory of glacial dams, the opposing hypotheses have given zest to the investigations to the degree of advancing our knowledge of the lake history.

In the survey of the beaches, besides the terrestrial deformation recorded, there seems to be no more important discovery than when the writer found how the Huron, Michigan and Superior waters (the Algonquin gulf or lake) originally emptied to the northeastward of the Huron basin in place of discharging into lake Erie; after which by the northeastern tilting of the land "the waters were backed southward and overflowed into the Erie basin, thus making the Erie outlet of the upper lakes to be of recent date."* This conclusion was established by the survey of the Algonquin beach which recorded the necessary tilting. The first survey was suspended near Balsam lake, where an overflow was found; and, accordingly, in the original announcement, the generalizations were not carried farther, although there was a lower depression in the vicinity of lake Nipissing, which was shortly afterwards made use of by Prof. Gilbert† and the writer. With the further elevation of the land, the lower beaches—partly measured at that time (1887-8), represented the surface of the Algonquin water discharging by the Nipissing route alone.‡ This has since been worked out by Mr. Taylor.§

Co-existing with the Algonquin gulf or lake was the Lundy gulf or lake, occupying part of the Erie basin, and extending into the Ontario, having substantially the same level. Both of these bodies of water extended much farther towards the northeast than their successors, although more contracted in the opposite directions—the effect of the more recent tilt-

*Proc. A. A. A. S., vol. XXXVII, 1888, p. 199.

†The History of the Nipissing River.

‡Deformation of the Algonquin Beach, cited before.

§The Ancient Strait of Nipissing. F. B. Taylor. Bull. Geol. Soc. Am., vol V, 1893.

ing of the land. Prior to the existence of these separate bodies of water, higher shore-lines were formed, and the great gulf or lake bounded by them was called the Warren water, which name the writer has defined as applicable to the great open water of the region, until after the formation of the Forest beach—its most perfect episode—after which it was dismembered into the Algonquin and Lundy waters.*

During the changing stages of Warren water, its configuration was somewhat varied but not sufficiently to call the water by a multiplicity of names, according to the changing levels. The old shore lines form prominent features, requiring nomenclature for the most important. And additional naming only adds confusion. Some of the beaches have been renamed by Mr. Leverett,† contrary to the usage of naturalists.

With the continued elevation of the land, the Algonquin water sunk to the level of the Nipissing beach (of Taylor) and the Lundy became dismembered, and formed an insignificant lake Erie.‡ In the Ontario basin, the water sunk to the Iroquois beach and lower levels, and Niagara falls had their birth, after the river had first been a strait. Remnants of beaches of that time were long ago observed, not only in the vicinity of Niagara, but also at the head of the lake. With the temporary pauses recorded, the waters of the upper level were speedily lowered to that of the Iroquois beach, and then the Niagara river descended only 200 feet, in place of 326 feet, as at present. The effect of this diminished descent upon the excavating power of the falls was first pointed out by the writer in 1888§ and published in 1889. With the continued lowering of the waters in Ontario basin, the descent of the Niagara increased to 80 feet more than at present, as first shown by Prof. Gilbert; but later, by the tilting of the earth's crust north of the Adirondack mountains, the outlet of the Ontario basin was raised, causing the backing of the waters, so as to reduce the descent of Niagara river to its present amount.

*High-level shores in the region of the Great Lakes, etc., cited before.

†On the correlation of the New York moraines with the raised beaches of lake Erie, by Frank Leverett. Am. Jour. Sci., vol. L, 1895. pp. 1-20.

‡Proc. A. A. A. S., 1888, p. 199.

§The Iroquois Beach, etc. Trans. Roy. Soc. Can., 1889, p. 132.

In 1886, after the third survey of Niagara falls (by Prof. Woodward), the rate of recession was found to be much greater than had formerly been supposed. Prof. Gilbert then made a short study of the falls, the conclusions concerning which are summed up as follows by that author:* "The problem admits of expression in an equation:

$$\text{Age of gorge} = \frac{\text{Length of gorge.}}{\text{Rate of recession of falls.}} - \text{Effect of antecedent drainage.} - \text{" " thinner limestone.} - \text{" " thicker shales.} - \text{" " higher fall.} - \text{" " more floating ice.} \pm \text{" " variation of detrital load.} \pm \text{" " chemical changes.} \pm \text{" " changes of river volume.}$$

"The catchment basin was formerly extended by including part of the area of the ice sheet; it may have been abridged by the partial diversion of Laurentian drainage to other courses." He had divided the length of the gorge by the maximum rate of recession, finding the product to be 7,000 years. If the equation be carefully examined, together with the cited quotation, all the important changing effects in the physics of the river would lessen the estimated age of the cataract below 7,000 years, except the effect "by partial diversion of the Laurentian drainage to other courses," of which no evidence was suggested; nor was any lengthening of time shown as necessary, by the long inferior hight of the falls. Henceforth, Prof. Gilbert was naturally quoted as an authority that the age of the falls was only 7,000 years. This conclusion did not satisfy the writer, who from the evidence of the beaches, especially the Iroquois,† found that the rate of recession must have been for long ages much less than now, on account of the inferior hight of the falls; and also on account of the greatly diminished volume of water, owing to the overflow of the upper lakes to the northeast, until in recent days. But how much of the work of the falls had been done

*The Place of Niagara Falls in Geological History. G. K. Gilbert. Proc. Am. Adv. Sci., vol. XXXV, 1886, pp. 222-223.

†See Trans. Roy. Soc. Can., 1889, p. 132; and Proc. A. A. A. S., 1888, p. 199.

before the upper lakes were turned into the Niagara drainage, for a long time seemed undeterminable, until the features of Foster's flats were used for measuring the amount of work performed in that early episode. This standard has since been confirmed by other phenomena not yet published; and from a different standpoint the distance of the early recession has been agreed to by Prof. Gilbert, who now considers the age of the falls far greater than that formerly suggested by his paper in 1886. From all the available data up to 1894, the writer computed the age of Niagara falls at 32,000 years.* Of the various episodes, that of the cataract passing the narrows of the whirlpool rapids still seems the most difficult of explanation; but the writer has recently found that the narrows record a second reduction in the amount of fall in the river, before the present descent was established, thus retarding the recession along this section of the gorge, and increasing in part the time compensation for the reduced amount of work performed. However, further discoveries are necessary to fully explain the phenomenon of the narrows. It now seems probable that the error in determining the time required for the recession of the falls through the section of the whirlpool rapids would not affect the computation of the whole age of the river by more than a few per cent.

No less important than the determination of the age of the river was that of the date when the waters of the Algonquin basin (Huron, Michigan and Superior) were first turned into the Niagara drainage, owing to the warping of the land, with the greatest rise occurring along an axis trending N. 28° E.† The date of the diversion of the waters of the upper lakes from the Ottawa to the Niagara valley has been computed by the writer at 7,200 years. This result was obtained from the mean of three distinct methods of computation, varying from 6,500 to 7,800 years.‡ Mr. F. B. Taylor's more recent estimate gives the range of from 5,000 to 10,000 years.

Niagara as a time piece would be incomplete without indi-

* Duration of Niagara Falls. Am. Jour. Sci., vol. XLVIII, 1894, pp. 455-472.

†This direction occurs east of Georgian bay, while at the end of lake Ontario the direction of rise is N. 25° E. See papers by the writer cited before.

‡See Duration of Niagara Falls, cited before.

cating the changes in the near future. From the northeastward tilting of the lake region, it was computed that in 5,000 years, not merely Niagara falls would cease to exist, but also that the drainage of the deepest part of the Niagara river at Buffalo (45 feet) would be reversed and turned into lake Erie, whose outlet would then be through lakes Huron and Michigan into the Mississippi river by way of Chicago. This inference was based upon the long delayed discovery of the rate at which the earth's crust has been rising in the lake region,—which was found to be for the Niagara district 1.25 feet per century more than the rate of rise at Chicago.* With this determination it was easy to calculate the rate of terrestrial deformation for other regions,—thus northeast of lake Huron the rise has been found to be two feet per century, and north of the Adirondacks, the warping is progressing at 3.75 feet in a hundred years.

The rate of deformation of 1.25 feet per century, in the Niagara district, was the minimum calculation, with a possible maximum of about 1.5 feet per century. The approximate correctness of the determination has just been confirmed by a paper presented to the American Association, by Prof. G. K. Gilbert, immediately before this communication was read.† He had used the bench-marks at various localities where the fluctuations of the lake levels have been registered the last 20-37 years. While the recorded measurements vary from about one to two and a half inches during the periods of observation, they have been extended over the lake region, with results closely agreeing with the previous determinations of the writer. This will be better understood using Prof. Gilbert's application—namely,—that in 500-600 years, the Erie waters would be on a level with those of lake Huron—in 1,000 years they would overflow the natural divide near Chicago—in 2,500 years, the waters would cascade into the Niagara gorge only during high water—and in 3,000 years, the falls would be entirely drained. These changing conditions, based upon the writer's previously discovered rate of terrestrial deformation, would take—720 years for the Erie and Huron waters to be

*See Duration of Niagara Falls, cited before.

†Modification of the Great Lakes by earth movements. Nat. Geog. Mag., vol. VIII, 1897, pp. 233-247.

on the same level; 1,280 years for the overflow into the Mississippi drainage (the artificial canal would reduce this estimate to 720 years); and 2,560 years for the general drainage of the lakes into the Mississippi. In 5,000 years, the whole river as far as Buffalo would be drained towards the south.

In spite of taking the minimum rate of recession and the probable errors the closeness of these results satisfactorily confirms many of the calculations based upon Niagara as a geological chronometer.

This paper, giving the principal results of investigations into the lake history, thus shows the writer to have been greatly affected by the studies of his co-workers. Indeed all of the researches by the different observers have been very much dove-tailed, so that our present knowledge of the history of the great lakes and Niagara falls is the result of the labors of many individuals. Besides the names of those already mentioned, we should add those of Shaler, Tarr, Wright, Russell, Upham, Kibbe, Lincoln, Brigham and Scovill, with the names of Hall and Lyell, too well known to need special mention.

To complete the review mention should be made of the writings of Mr. F. B. Taylor, in connection with his important survey of the Nipissing outlet of the Algonquin basin, and of the dissected shore lines of the upper lakes; and of the important investigation of Central New York by Prof. Fairchild.